

# Tracking Operations During the Helios 1 Launch Phase

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*Tracking operations during the Helios 1 launch phase proceeded quite smoothly and contributed to a very successful launch. Key features considered in the Helios 1 pre-launch planning were the possible "silent spacecraft" mode and the spacecraft low-gain antenna "interference zone," although in the actual launch the former did not occur and the impact of the latter was negligible. This report details the pre-launch planning and post-launch analysis of tracking operations during the Helios 1 launch phase.*

## I. Introduction

The Helios 1 spacecraft was launched from Cape Canaveral on December 10, 1974, at 07:11:01.537 Greenwich Mean Time (GMT), at a Launch Azimuth of 98.9 deg. The purpose of the Helios 1 mission, a joint undertaking of the Federal Republic of West Germany and the United States of America, is to study the properties of the Sun from a close range. To accomplish this goal, the Helios 1 spacecraft was lofted into an elliptical heliocentric orbit by a combination Titan III-D, Centaur, TE-364-4 launch vehicle in the parking orbit ascent mode. Heliocentric orbit injection occurred over the southern tip of Africa, and the resulting near-Earth trajectory was such that within the Deep Space Network (DSN), the Australian complex was first to view the

spacecraft post-injection. The Deep Space Station (DSS) selected to perform the initial acquisition was Weemala (DSS 42), with Honeysuckle Creek (DSS 44) as a backup. Two features of the Helios 1 spacecraft sharply distinguished the preparations for and the execution of this initial acquisition from previous but otherwise similar initial acquisitions at DSS 42—the possible "Silent spacecraft" or "radio frequency safe" mode and the spacecraft low-gain antenna orientation "interference zone." These are briefly described below.

### A. Helios 1 "Silent Spacecraft" Mode

If the Helios 1 spacecraft experiences a power drop, the spacecraft transmitter is automatically turned off. To reactivate the transmitter, it is necessary to acquire the

uplink (in the “blind”) and subsequently command the transmitter back on. Obviously, this adds a whole new dimension of uncertainty to the initial acquisition process, viz:

If a signal is not detected, is it because the ground antenna is correctly pointed but the spacecraft is in the silent mode, or is the ground antenna not properly pointed at the spacecraft in the normal transmitting mode? The same question exists in regard to the proper ground receiver settings, etc.

## B. Helios 1 Low-Gain Antenna “Interference Zone”

During the time period shortly after DSS 42 rise, the spacecraft low-gain antenna orientation would be such as to produce very deep nulls, with the resultant effect that for an approximate 4-min period the spacecraft/ground communications might become either marginal or totally impossible. Obviously, this event would inject a great deal of uncertainty and disruption into the more normal, orderly progression of events at a DSS during an initial acquisition, typically: acquire one-way downlink, antenna to auto-track, antenna to aided track, transmitter on, sweep to acquire uplink, reacquire two-way downlink, antenna return to auto-track, etc.

In the following sections, the pre-launch tracking operations planning, which was heavily impacted by the two Helios-peculiar features described above, and the subsequent analysis of the launch tracking operations at DSS 42, will be detailed.

## II. Helios 1 Trajectory Considerations

The nominal open window Helios 1 launch trajectory for December 10 resulted in only moderate angular and frequency rates, which were very typical of previous mission parking orbit ascent-type launch trajectories over Australian stations. Maximum angular and frequency rates were as follows:

$$\frac{d}{dt} \{D2\} \approx 320 \text{ Hz/s (S-band level)}$$

$$\frac{d}{dt} \{XA\} \approx 1.5 \text{ Hz/s (voltage-controlled oscillator (VCO) level)}$$

$$\frac{d}{dt} \{HA\} \approx 0.1 \text{ deg/s}$$

where

$D2$  = two-way doppler frequency

$XA$  = spacecraft receiver best lock, with doppler accounted for

$HA$  = local (station) hour angle

Figure 1 stereographically illustrates the Helios 1 launch pass over DSS 42, while Fig. 2 details the elevation angle versus time and Fig. 3 the  $XA$  frequency versus time. The duration of the pass was approximately 5 h and 50 min, with the retrograde point, defined by:

$$\frac{d}{dt} \{HA\} = 0$$

occurring at 08:45:00 GMT.

A necessary facet of information to the determination of the initial acquisition strategy for the Helios 1 launch was the expected uncertainties in tracking observables as translated from the expected uncertainties in the launch vehicle performance. M. Traxler (at the Air Force Eastern Test Range (AFETR)) indicated that  $3\sigma$  trajectory dispersions for the Helios 1 launch could be approximated by perturbing the nominal trajectory injection conditions with the following quantities:

$$\Delta X_i = 30 \text{ km}, \quad i = 1, 3$$

$$\Delta \left\{ \frac{dX_i}{dt} \right\} = 0.1 \text{ km/s}, \quad i = 1, 3$$

Tracking prediction observables could then be generated on the nominal and the perturbed trajectories, and the resultant approximate  $3\sigma$  tracking observable uncertainties obtained by differencing the two. This procedure was performed on three different launch trajectories, and the maximum approximate  $3\sigma$  uncertainties in tracking observables were determined to be:

$$\Delta HA \approx 1.15 \text{ deg}$$

$$\Delta dec \approx 0.80 \text{ deg}$$

$$\Delta \text{uplink} (XA) \approx 17 \text{ Hz (at VCO level)}$$

Additionally, the following approximate  $3\sigma$  frequency uncertainties for the Helios 1 spacecraft receiver were assumed:

$$\Delta \text{uplink} (\text{best lock}) \approx 12 \text{ Hz (at VCO level)}$$

$$\Delta \text{uplink} (\text{temperature}) = \Delta T \left\{ \frac{\partial}{\partial T} [\text{uplink}] \right\}$$

$$\approx 10 \text{ Hz (at VCO level)}$$

Combining the trajectory, best lock, and temperature effects, above, one obtains a total approximate  $3\sigma$  uncertainty in the uplink frequency of:

$$\Delta_{\text{uplink}} \approx 23 \text{ Hz (at VCO level)}$$

These angle and frequency  $3\sigma$  uncertainties were relatively small, and tended to counterbalance the difficulties posed by the possible silent spacecraft mode and the antenna interference zone in formulating the Helios 1 initial acquisition plan. In the following two sections, the angle drive strategy and frequency acquisition strategy are described.

### III. Angle Drive Strategy at DSS 42

In a more typical and less complicated launch phase, the overriding emphasis insofar as the angle drive mode is concerned is to achieve auto-track as soon as possible, as the near-Earth phase is the only phase wherein angular tracking data are a powerful radio metric data type for high-precision orbital determination processing. However, the Helios 1 launch case was strongly impacted by both the silent spacecraft mode and the antenna interference zone for the following reasons:

- (1) In the silent spacecraft mode, one would have to drive the antenna to the spacecraft in the blind for a long enough period to acquire, establish uplink, and subsequently command the spacecraft on.
- (2) If one were able to achieve auto-track fairly soon after spacecraft rise, there would exist a strong possibility of losing it (auto-track) shortly thereafter, because of low-signal strength and signal-to-noise ratio (SNR) during the interference zone. Additionally, in the process of losing auto-track and driving the ground antenna off the spacecraft, one might easily lose downlink lock.

Therefore, the basic angle drive strategy would be to (computer) drive the ground antenna with the best predicts available until at least after the nominal end of the defined interference zone. Fortunately, because the angular  $3\sigma$  uncertainties (discussed in Section II) were so small, no angular "search" schemes were deemed necessary to achieve a very high probability of a successful early acquisition. The hierarchy of decision for the angle drive mode, which was most heavily dependent on the

availability of differing sets of tracking predictions, was as follows:

- (1) **Phase I—Local horizon to the end of the interference zone** (prior to rise, the antenna to be positioned at the rise point)

- (a) *Applicable condition:* Launch occurs within several seconds of the daily open window launch time.

*Antenna drive mode:* A preflight nominal Antenna Pointing Subsystem (APS) drive tape in GMT.

- (b) *Applicable condition:* Launch does not occur at the open window launch time, but a verified APS drive tape generated from the actual launch time is available at DSS 42 prior to rise.

*Antenna drive mode:* Actual launch time APS drive tape in GMT.

- (c) *Applicable condition:* Launch does not occur at the open window launch time, and a verified drive tape based on the actual time is not available at DSS 42 before rise, but actual launch time page print predictions are available.

*Antenna drive mode:* Preflight nominal APS drive tape in time from launch (TFL) in conjunction with a manually entered  $\Delta t$  offset equal to the actual launch time in GMT. Angle offsets to be manually entered to correct antenna position to actual launch time page print predictions.

- (d) *Applicable condition:* Launch does not occur at the open window launch time and no actual launch time based predictions are available at DSS 42 prior to rise.

*Antenna drive mode:* Preflight nominal APS drive tape in TFL with a manually entered  $\Delta t$  offset equal to the actual launch time in GMT. Angle offsets to be provided to DSS 42 by the Tracking Network Operations Analyst, via voice.

- (2) **Phase II—End of interference zone to verified uplink acquisition**

- (a) *Applicable condition:* The spacecraft known to be in the silent mode (as determined by AFETR and transmitted to the Mission Control and Computing Facility (MCCF)).

*Antenna drive mode:* Continue as in Phase I.

- (b) *Applicable condition:* The spacecraft not known to be in the silent mode but downlink has not been acquired by DSS 42.

*Antenna drive mode:* Continue as in Phase I.

- (c) *Applicable Condition:* DSS 42 has obtained good downlink lock.

*Antenna drive mode:* Proceed as follows:

- (i) Antenna to auto-track on the Acquisition Aid Antenna, (S-Band Acquisition Antenna (SAA), Receiver 2).
- (ii) Acquire and confirm receiver lock on the main antenna (S-Band Cassegrain Monopulse (SCM) feed cone, Receiver 1).
- (iii) Antenna to auto-track on SCM.

(3) **Phase III—Post verified uplink acquisition**

- (a) *Applicable condition:* The downlink was previously not acquired.

*Antenna drive mode:* Proceed as in 2.c.

- (b) *Applicable condition:* The downlink had previously been acquired and auto-track established.

*Antenna drive mode:* Proceed as is.

## IV. Uplink Acquisition Strategy at DSS 42

The only (and minor at that) impact of the possible silent spacecraft mode and the antenna interference zone on the uplink acquisition strategy was the necessity of waiting until the end of the interference zone before attempting the uplink acquisition. Otherwise, the uplink acquisition was expected to be quite routine, particularly when considering the small  $3\sigma$  uncertainties presented in Section II. The basic characteristics of the uplink acquisition strategy are as follows:

- (1) The uplink acquisition to consist of a single uplink frequency sweep in the direction of XA change, advantageously placing the ending Track Synthesizer Frequency (TSF) near the XA frequency, and thus satisfying a command capability requirement that the difference between TSF and XA be no greater than 110 Hz at VCO level. The end point of the sweep becomes TSF for the remainder of the pass, with no additional tuning required.
- (2) The uplink sweep range to be approximately XA  $\pm 100$  Hz (at VCO level).

- (3) The uplink sweep rate to be +180 Hz/min (at VCO level), resulting in an effective rate as seen by the spacecraft receiver of approximately +150 Hz/min (spacecraft receiver rate = uplink sweep rate - spacecraft (XA) rate).
- (4) The duration of the sweep as defined above to be approximately 80 s.
- (5) On each given launch date, a sweep start time to be fixed (in TFL) at a time shortly after the end of the interference zone. This sweep start time (in TFL) to remain unchanged throughout the daily launch window for each particular launch date.

For the actual launch on December 10, 1974, the uplink acquisition sweep selected according to the above guidelines was as follows:

Ramp start time = 08:05:00 GMT

Starting frequency = 22.039080 MHz (VCO)

Frequency rate = 3 Hz/s (VCO)

Ramp end time = 08:06:30 GMT

Ending frequency = 22.039350 MHz (VCO)

This uplink sweep pattern can be seen in Fig. 4.

## V. Post-Flight Analysis of the Helios 1 Launch Phase

### A. The Helios 1 Silent Spacecraft Mode

No information was received from the down range AFETR stations that the Helios 1 Spacecraft was in the silent mode, and, in fact, this was apparent moments after the expected rise at DSS 42, when a one-way downlink was routinely acquired. Obviously, this condition vastly reduced the uncertainties heretofore inherent to the initial acquisition procedure at DSS 42.

### B. Interference Zone Results

The maximum effects of the interference zone were predicted to occur between:

08:01:00 and 08:05:00 GMT

Figure 5 shows the downlink signal strength at Receiver 2, on the SAA, while Fig. 6 shows the signal strength at Receiver 1, on the SCM, both figures encompassing the above time period. As can be seen in these data, the maximum interference zone signal strength

degradation on Receiver 2 (SAA) was approximately 6 dB, while on Receiver 1 (SCM) it was approximately 8 dB, both of these losses being considerably less than was generally anticipated. Further, this degradation in signal strength was such that neither receiver lost lock during the entire interference zone period, although there was also a very substantial degradation in SNR during this period. An interesting feature which can be seen in Fig. 6 (SCM) is the sudden increase in signal strength at 08:05:20 GMT, whereas no such increase occurs at this time in Fig. 5 (SAA). At this time, the antenna went to auto-track, previously having been computer-driven according to nominal predictions. The nominal predictions being used were in error by approximately:

$$\Delta HA \approx 0.11 \text{ deg}$$

$$\Delta dec \approx 0.08 \text{ deg}$$

$$\Delta \text{total angle error} \approx 0.14 \text{ deg}$$

Since the half-power offset for the SCM is 0.18 deg, one would expect a loss of roughly 1.8 dB for 0.14-deg error, and that is almost exactly the effect seen in Fig. 6. On the other hand, the SAA has a half-power offset of 8 deg, so the elimination of the 0.14-deg pointing error at 08:05:20 GMT would have no perceptible effect—hence, no effect is seen in Fig. 5 at the time of onset of auto-track.

The net effect of the antenna interference zone was far less traumatic than had (conservatively) been expected, and, since the worst case had been completely planned for in any event, the initial acquisition at DSS 42 was not in any substantial way adversely impacted by the effects of the antenna interference zone.

### C. Preflight Prediction Accuracy

In the early portion of the pass at DSS 42, the actual radio metric data, when differenced with the preflight nominal predictions (generated from the actual liftoff time), yielded the following residuals (as obtained from the near-realtime pseudo-residual program):

$$\Delta HA \approx 0.11 \text{ deg}$$

$$\Delta dec \approx 0.08 \text{ deg}$$

$$\Delta XA \approx 1.0 \text{ Hz (VCO)}$$

These can be compared to the estimated  $3\sigma$  uncertainties presented in Section II as:

$$\Delta HA \approx 1.15 \text{ deg}$$

$$\Delta dec \approx 0.80 \text{ deg}$$

$$\Delta XA \approx 17 \text{ Hz (VCO)}$$

As can be seen, the actual errors which occurred were approximately 10% of the estimated  $3\sigma$  uncertainties, which would seem to (probabilistically) indicate that the estimation of the uncertainties was on the conservative side, a not wholly undesirable condition.

### D. One-Way Downlink Acquisition at DSS 42

The one-way acquisition of the Helios 1 downlink by DSS 42 was executed rapidly and with no complications. Rise occurred at:

07:57:14 GMT

and DSS 42 had good, one-way lock at:

07:57:24 GMT

or ten seconds later. This acquisition can be seen in Fig. 7. The station apparently set its receivers slightly below the expected frequency (the receiver frequency being inversely related to doppler frequency) and allowed the downlink to “walk” down into the receivers—quite successfully!

### E. Uplink Acquisition at DSS 42

The instructed uplink acquisition sweep was defined as:

Ramp start time = 08:05:00 GMT

Starting frequency = 22.039080 MHz (VCO)

Frequency rate = 3 Hz/s (VCO)

Ramp end time = 08:06:30 GMT

Ending frequency = 22.039350 MHz (VCO)

Sweep duration = 90 s

The instructed sweep and the sweep actually executed by DSS 42 can be seen in Fig. 4. As can be seen, the station tuned (manually) at about 90% of the instructed rate, a quite creditable performance, particularly when compared to the DSS 42 performance during the Mariner Venus/Mercury 1973 (MVM '73) launch, when the station was able to achieve a sweep rate of only approximately 60% of that instructed. Since the spacecraft was in the noncoherent mode, it was not immediately possible to tell exactly when or even if the uplink had been acquired—however, the fact that the uplink

sweep had been routinely successful became known via telemetry some minutes later. At 08:26:31 GMT, the downlink was reacquired as good, coherent two-way, in response to a prior command to that effect.

#### **F. Angle Tracking**

In accordance with the angle drive strategy detailed in Section III, the antenna at DSS 42 was initially computer-driven to the preflight predictions generated from the actual launch time. At 08:06:20 GMT, or approximately one minute after the earliest possible (instructed) time, the antenna was successfully switched to auto-track on the SCM.

## **VI. Summary of Tracking Operations During the Helios 1 Launch Phase**

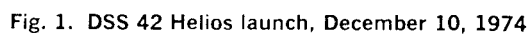
Key spacecraft features considered in the pre-launch planning for the Helios 1 launch phase were:

- (1) The silent spacecraft mode.
- (2) The low-gain antenna orientation interference zone.

In the actual launch the silent spacecraft mode did not occur, and the interference zone was considerably less difficult than expected; nonetheless, tracking operations at DSS 42 during the launch phase proceeded exactly as planned, and were highly successful.

## **Acknowledgment**

The authors wish to acknowledge R. Allis, the Telemetry Network Operations Analyst, for providing the downlink signal strength data during the interference zone.



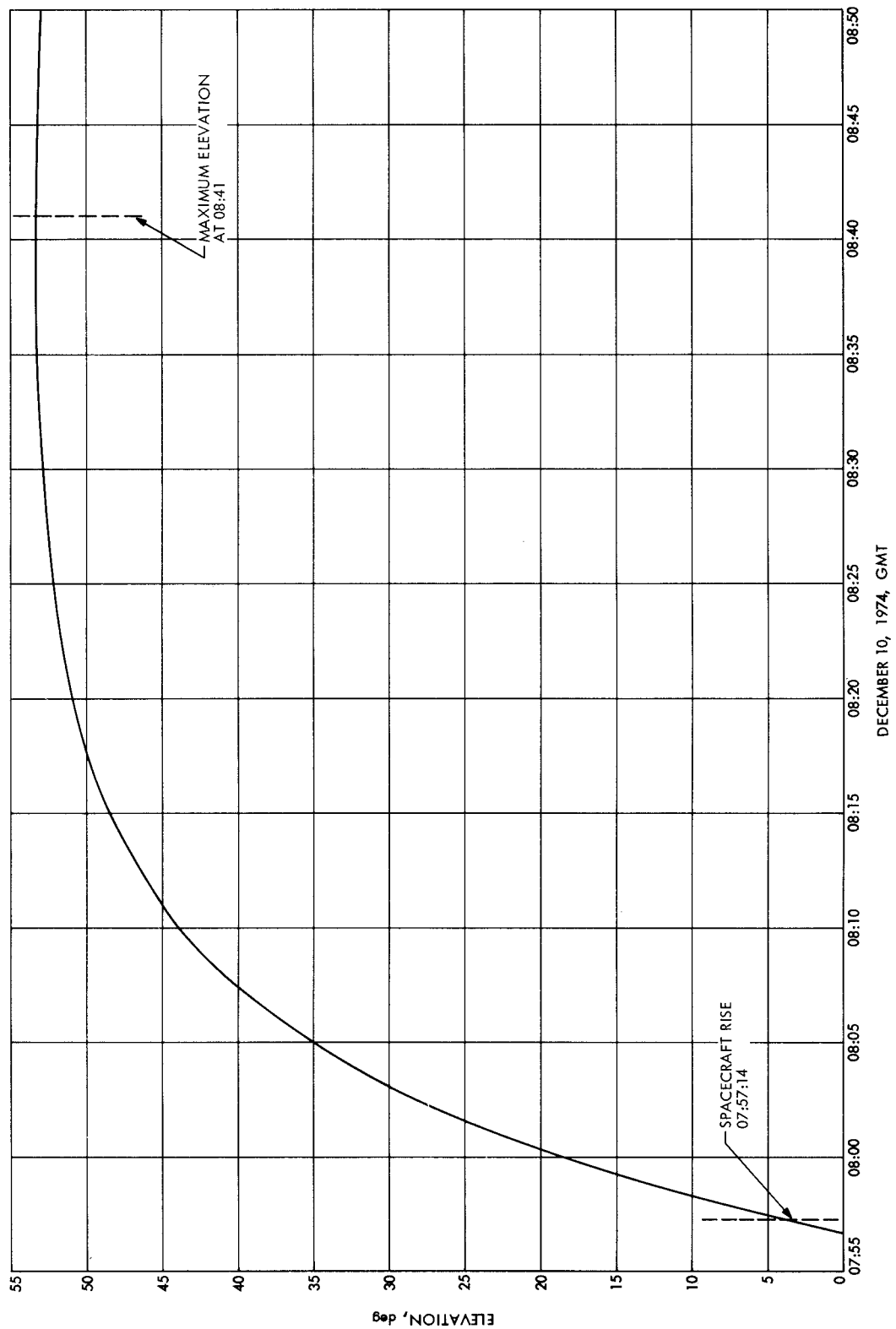


Fig. 2. Spacecraft elevation at DSS 42 Helios launch



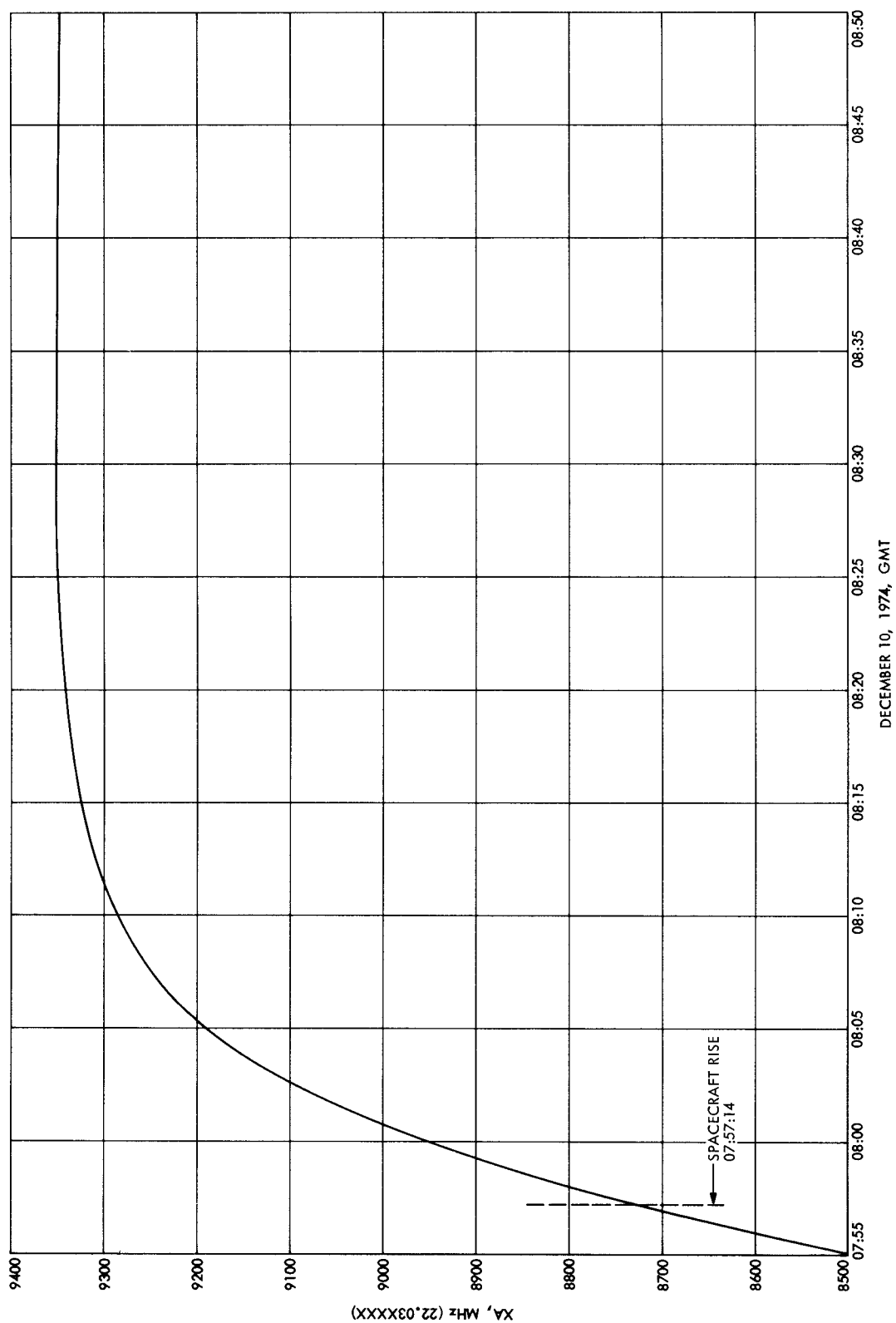


Fig. 3. Best-lock frequency at DSS 42 Helios launch

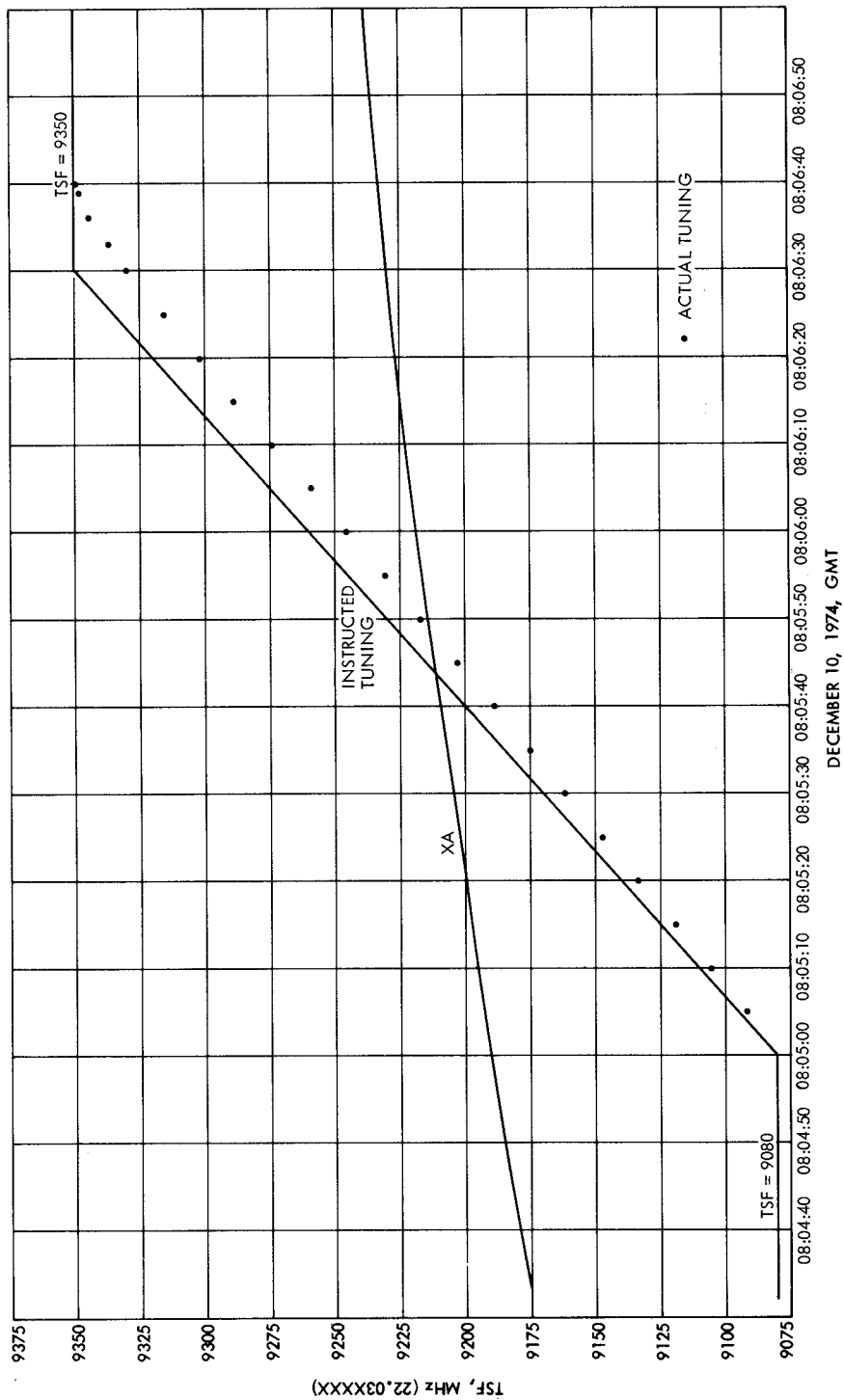


Fig. 4. Comparison of actual tuning to instructed tuning for DSS 42 Helios launch

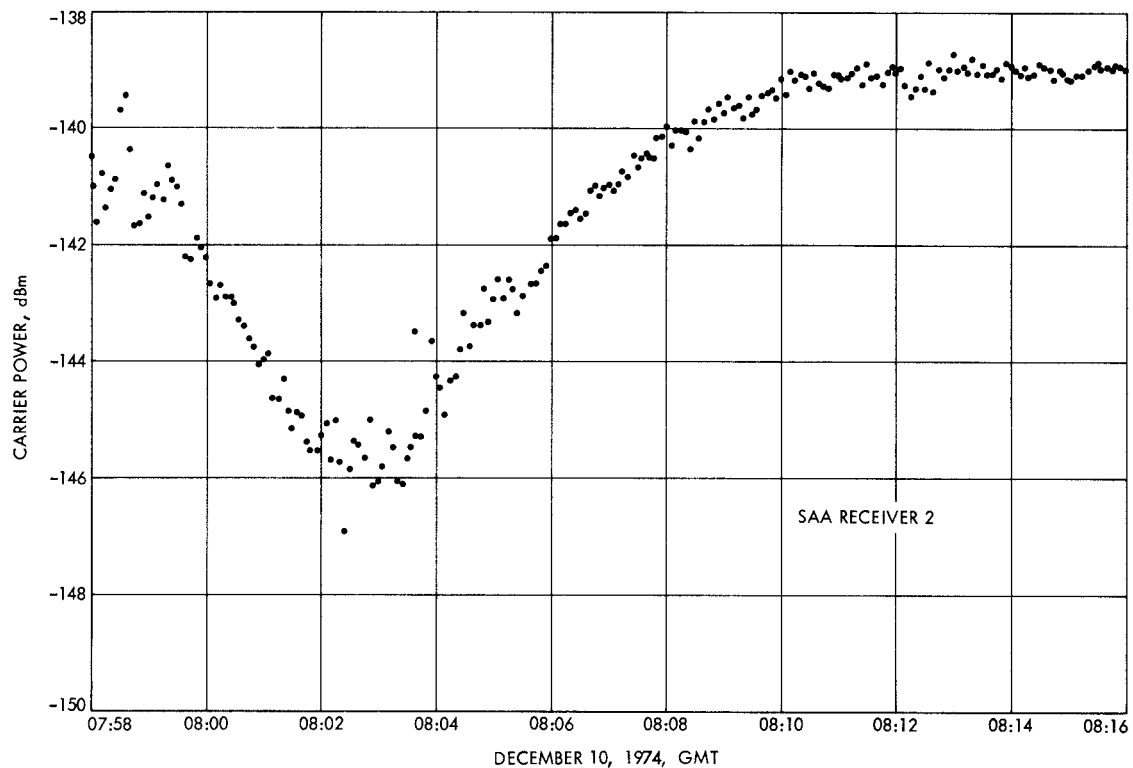


Fig. 5. Interference zone signal strength (SAA) at DSS 42 Helios 1 launch pass

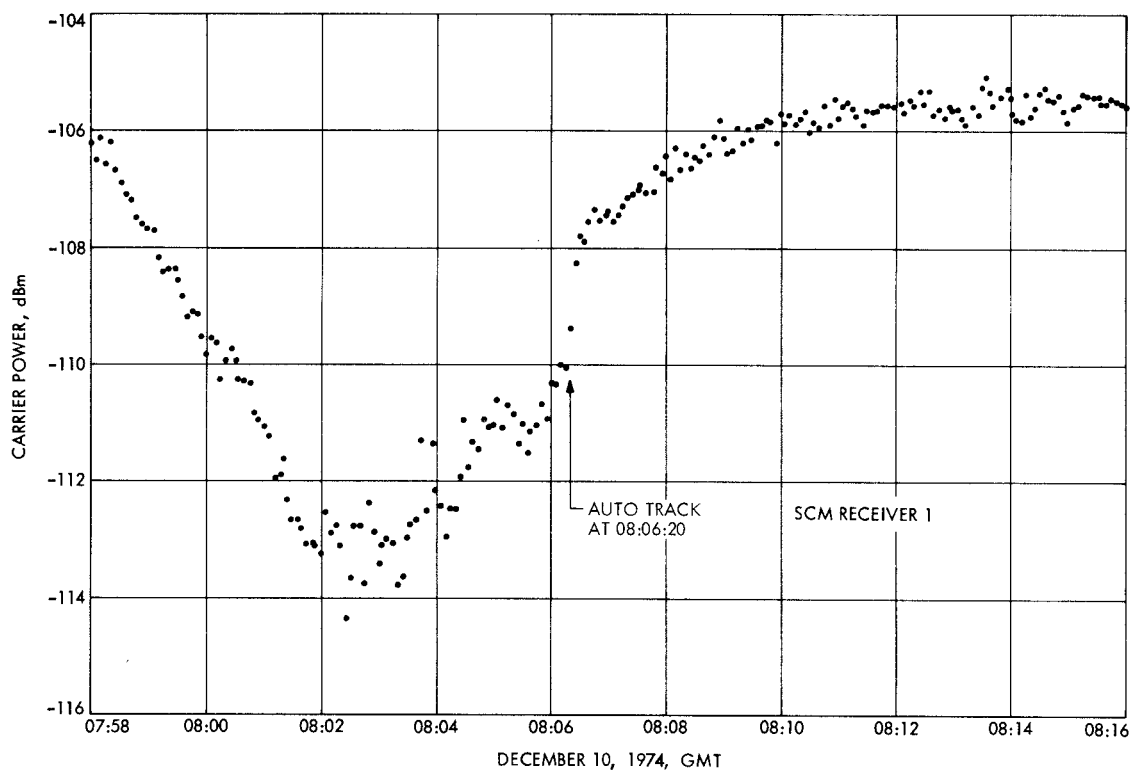


Fig. 6. Interference zone signal strength (SCM) at DSS 42 Helios 1 launch pass

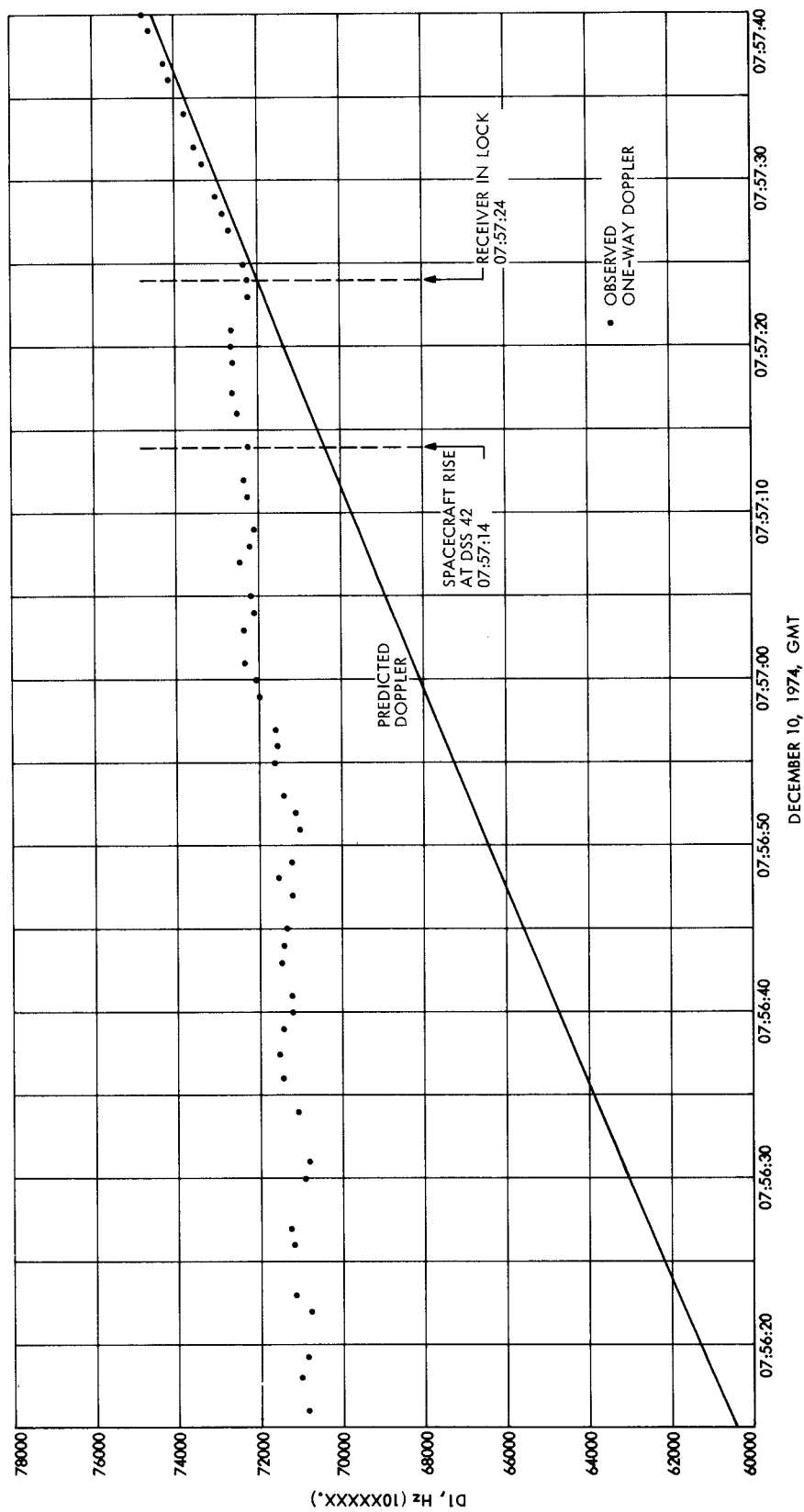


Fig. 7. Initial downlink acquisition during DSS 42 Helios launch